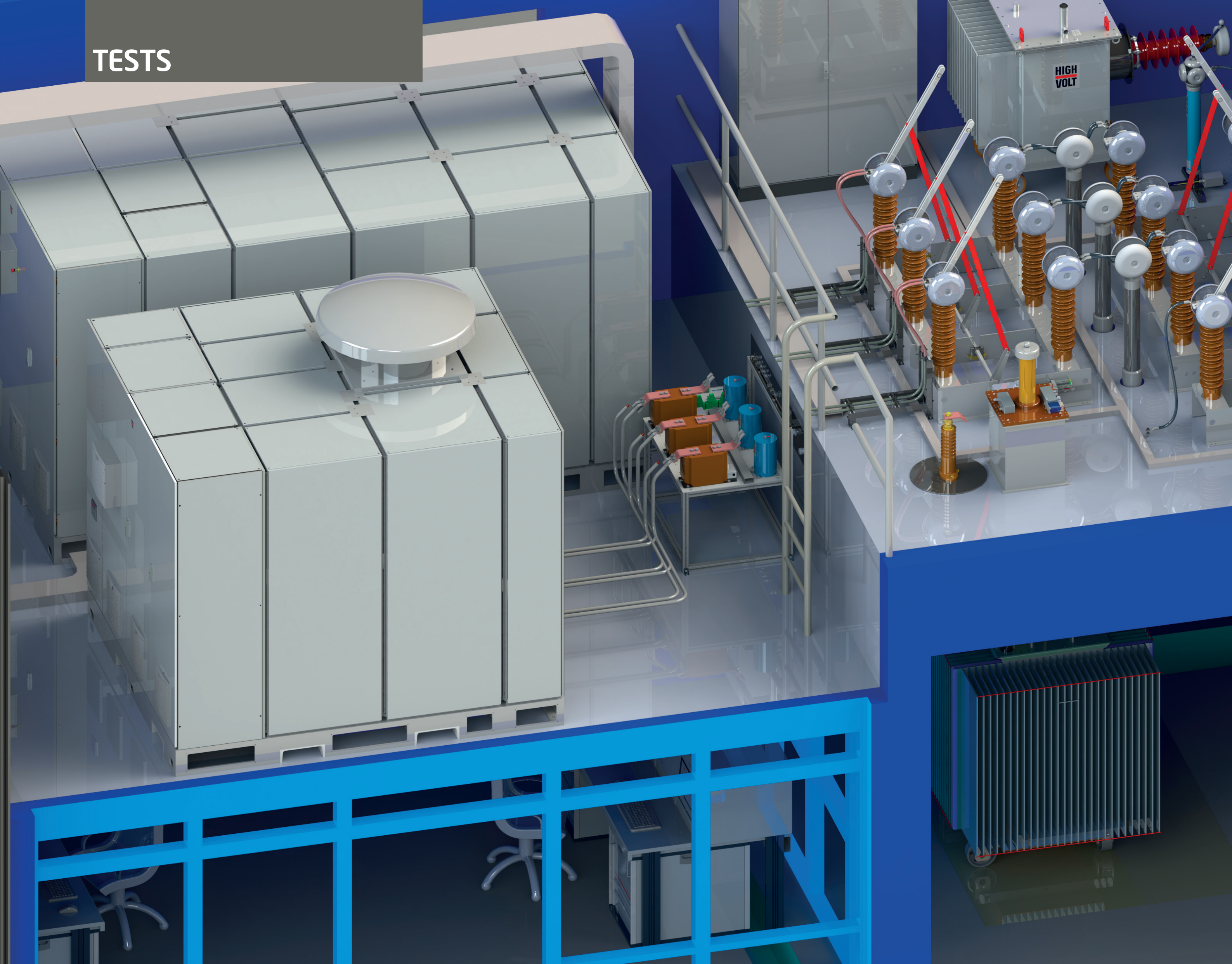


Automated test systems for distribution transformers – Part II

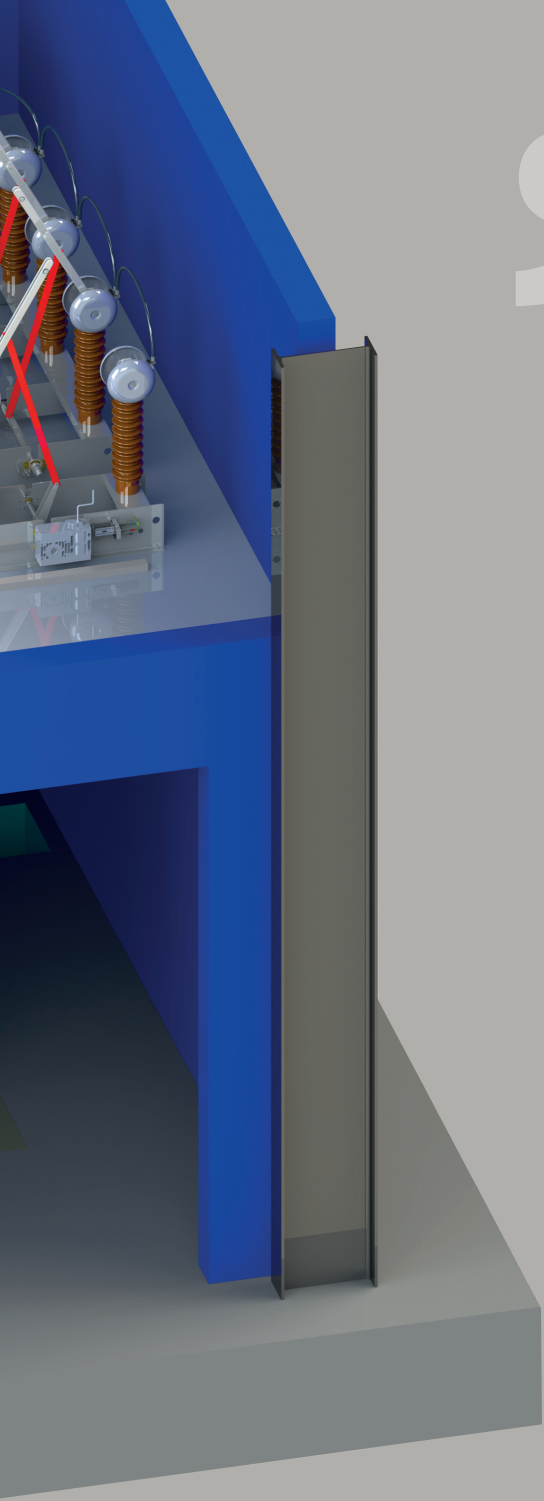
Detailed analysis of the test system features

ABSTRACT

Distribution transformers are used worldwide and in very large quantities as a link between regional medium-voltage networks and local low-voltage distribution systems. To ensure quality, the required electrical characteristics must be demonstrated through extensive testing procedures on each distribution transformer in the production. This paper gives an overview of the equipment for automated testing of distribution transformers. There are also various options presented for a significant reduction of the required test time which can be achieved by optimizing the interaction of automatic switching devices, intelligent system control and largely intuitively designed test sequences.

KEYWORDS

automated testing, distribution transformer, transformer testing, high-voltage test equipment, factory testing



More significant reductions of the time requirements are possible through reducing both the initial set-up time of the system and reconfiguration time between individual tests

5. Time needed for routine tests

The time needed to conduct a full routine test of a distribution transformer mainly comprises the following elements:

- Set-up time for the test system
- Total time needed for the individual tests
- Time needed for the reconfiguration of the test system and reconnection of the transformer under test between individual tests
- Time needed for documentation of the measurement results

There is only very limited scope for influencing the total time needed for the individual tests, as most aspects of the test procedure and its duration are defined in IEC standard IEC 60076-3 [2].

In terms of the *separate source voltage withstand test*, some manufacturers shorten the effective test duration per unit by simultaneously supplying the test voltage to multiple transformers that are connected in parallel. This method, however, comes with the risk that a weak insulation in one unit, which would become manifest as a rise in the test current, can easily be overlooked. However, insulation failure with a full breakdown would be reliably detected, as the test current would suddenly rise sharply and the test voltage would break down.

More significant reductions of the time requirements are possible through reducing both the initial set-up time of the system and the reconfiguration time between the individual tests. Automated switch-over using motor-driven high-voltage switches would be one way of saving time in a significant order of magnitude. To show this, testing with manual clamping of electrical contacts of the transformer under test will be compared with testing using automated switch-over. The time needed for different pre-tests, e.g. of the insulation resistance, DC winding resistance, vector group etc., will not be considered here. These pre-tests can be conducted on a separate test station to save time.

6. Testing with manual clamping

When routine tests are conducted in a transformer test field where the contacts are manually clamped to the transformer under test, the following steps must be performed as a minimum before each test:

- De-energising the test field
- Accessing the cordoned-off safety area
- Taking protective measures to prevent electrical hazards (shorting and earthing)
- Disconnecting contacts to be modified on the transformer under test
- Making the new contacts on the transformer under test
- Removing the protective measures (earthing rod)
- Closing the barriers of the safety area
- Switching on the test field

To estimate the number of disconnecting/reconnecting actions, Fig. 5 shows typical connection options for the individual routine tests. Only one connection option can be used at a time.

The upper part of the diagram shows the connections required for the *separate-source voltage withstand test* (7), where the voltage is supplied to the high-voltage side of the transformer under test (6). All of the three phases on the high-voltage side are jointly connected to the high-voltage transformer (5) of the test system. The connections of the low-voltage side are shorted and earthed for this test.

Much lower voltages are required for the *separate-source voltage withstand test* on the low-voltage side; they can be tapped directly from the step-up transformer (2) of the test system. For this, the three phases of the low-voltage side of the transformer under test are connected to the test system (9), and the high-voltage side (10) is shorted and earthed. An automatic switch in the test system connects the three contacts with the single-phase test voltage.

With load loss test, particular attention must be paid to establishing reliable connections on the low-voltage side with the lowest possible contact resistance

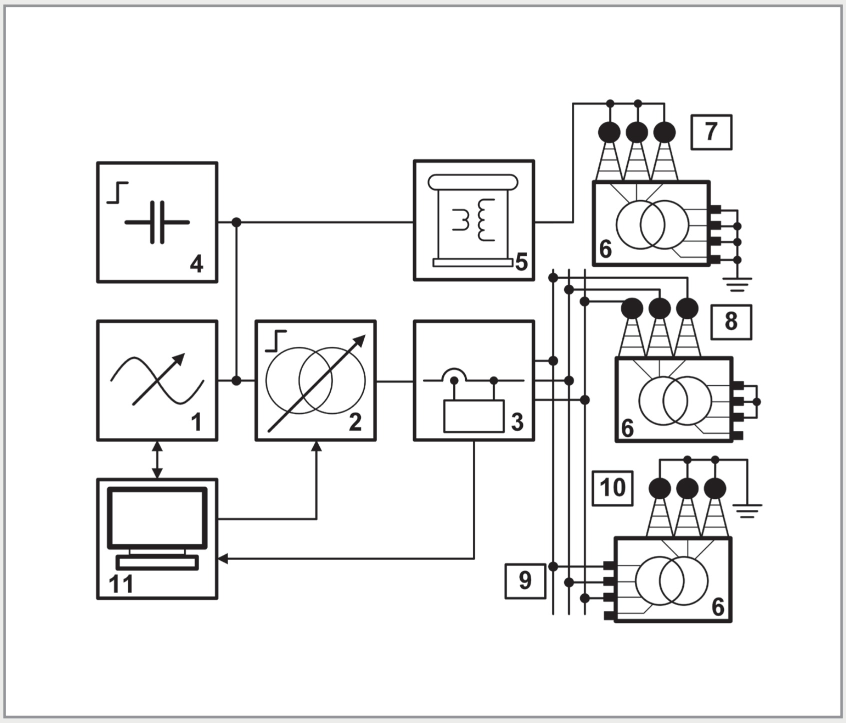


Figure 5. Testing with manual clamping

Once the connections on the high-voltage side (10) are removed, the *induced voltage test* can be started. For this, a voltage of about twice the nominal voltage and at least twice the nominal frequency is supplied to the low-voltage side. This can be followed by a *no-load test* without the need to reconfigure the connections. The no-load current and the losses of the laminated core are determined during this test. In order to avoid any bias of the measurement result through any pre-magnetisation that may be present, the *no-load test* is typically started at a voltage that is higher than the nominal voltage, and the voltage is then gradually reduced to the nominal voltage level. *No-load tests* are carried out at the nominal frequency of the transformer under test.

Now, to determine the load losses in a *load loss test,* the connections need to be reconfigured again (8). The test voltage is supplied to the high-voltage side. The phase connections on the low-voltage side are shorted using a flexible cable that is as short as possible and whose cross section is as large as possible, because this test is conducted at the nominal current of the transformer. The load loss that is measured on the high-voltage side includes both the losses in the transformer itself and the losses in the short-circuit bridge and contact resistances. For this reason, particular attention must be paid to establishing reliable connections on the low-voltage side with the lowest possible contact resistance. This requirement can generally only be satisfied through correspondingly high contact forces that ensure a sufficiently high contact pressure.

When the described sequence of steps is followed, the test field needs to be accessed five times, and the contacts of the transformer under test need to be connected and disconnected again seven times altogether.

If the transformer test field is equipped with motor-driven high-voltage switches that permit automated switch-over of the test circuitry, the number of manual steps carried out by the test personnel can be reduced dramatically

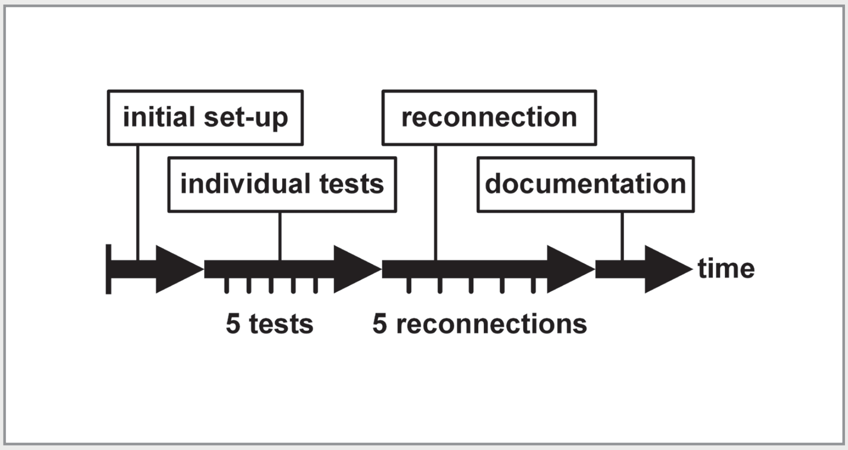


Figure 6. Test time for manual clamping

7. Testing with automated switch-over

If the transformer test field is equipped with motor-driven high-voltage switches that permit automated switch-over of the test circuitry, the number of manual steps carried out by the test personnel can be reduced dramatically. Once the contacts on the high-voltage and low-voltage sides of the transformer under test are connected with the test system, the test field does not have to be accessed again between the individual tests. Consequently, not only can the time needed to rearrange the contacts be saved, but also the time needed to take the protective measures to prevent electrical hazards and the time to repeatedly disconnect and reconnect the power supply of the test system is no longer necessary.

Figure 7 shows a possible circuit arrangement for automated contacting. The contacts of the distribution transformer (10) under test are connected with the test system using flexible cables. For typical three-

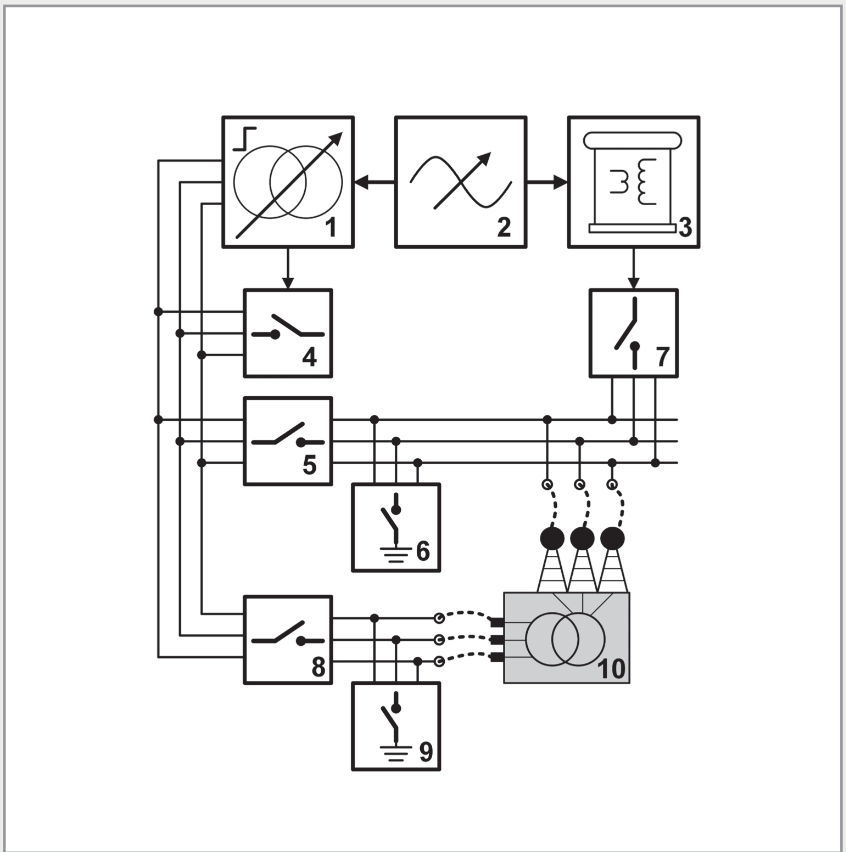


Figure 7. Arrangement for automated contacting

With the six motor-driven switches all of the mentioned test circuit arrangements can be set up without manual intervention

phase distribution transformers only the phase-contacts have to be connected to the test system [5]. For single-phase objects, a separate connection point is provided for connecting the neutral conductor. This additional connection is not shown in Fig. 7 for clarity. The switches that are shown in the diagram are typically arranged above the test room, in order to reduce the space requirements of the test system on the one hand and, even more importantly, to keep the connection cables as short as possible on the other. The inverter system (2), which includes both the required filter stages and the elements of the capacitive reactive power compensation, is optionally used here again to feed a step-up transformer (1) or the additional high-voltage transformer (3). These connections are established automatically via low-voltage contactors.

With the six motor-driven switches (4) to (9), all of the mentioned test circuit arrangements can be set up without manual intervention. The switch positions for the individual tests on both high-voltage and low-voltage side are listed in Fig. 8 below. This arrangement is especially developed for an efficient testing of two-winding distribution transformers. For special transformers with more winding systems (e.g. two separate LV windings or even more like traction transformers with multiple separate windings for rail applications) adapted arrangements of motor-driven switches are used for best fitting of the requirements of the test.

When testing a distribution transformer for the 36-kV medium-voltage grid, the required voltage rating of the switches (5), (6) and (7) on the high-voltage side is typically about 70 kV (line-earth for the *separate-source voltage withstand test*, and 72 kV (line-line for the *induced voltage test*) [2]. The required rating of the other switches (4), (8) and (9) does not exceed 5 kV.

Since all switching operations are performed at zero voltage, and switching arcs do not have to be extinguished, inexpensive motor-driven open isolating switches would be appropriate both from a technical and cost point of view. However, the contacting systems of standard isolating switches that are used in general power supply applications only allow an inadequately low number of switching cycles to be executed, typically between 1,000 and 2,000 cycles. By contrast, an automated transformer test field is dimensioned

Test	Switches closed HV	Switches closed LV	Typical test time
applied voltage HV	7	9	60 s
applied voltage LV	6	4 + 8	60 s
induced voltage	-	8	60 s
no-load	-	8	15 s
load-loss	5	9	15 s

Figure 8. Switch positions for the individual tests

The time needed to establish a new test circuit arrangement is only limited by the switching time of the motor-driven switches, which is much shorter than a mechanical reconfiguration by the test personnel

Central evaluation of the test results of produced transformers can open up many additional possibilities for quality assurance

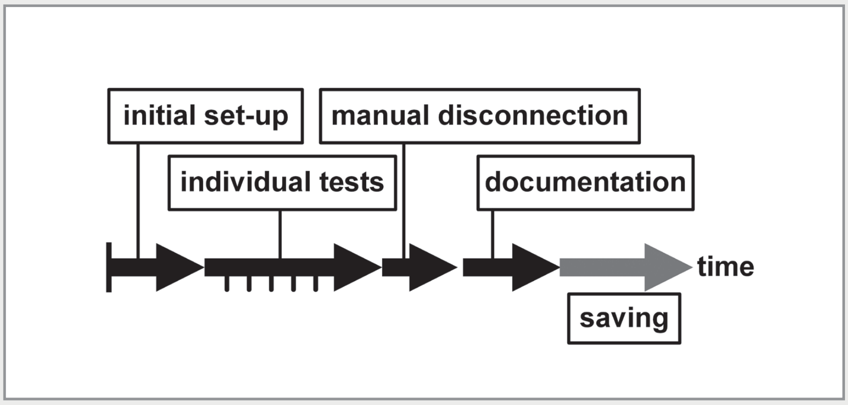


Figure 9. Test time with automated switch-over

for up to 10,000 transformers to be tested per year. To minimise the maintenance costs for the isolating switches, special disconnectors are used that have a service life of more than 100,000 cycles. Specially designed combinations of low-wear contact materials are used in such switches, and very high-quality actuating elements and bearings make for high mechanical reliability.

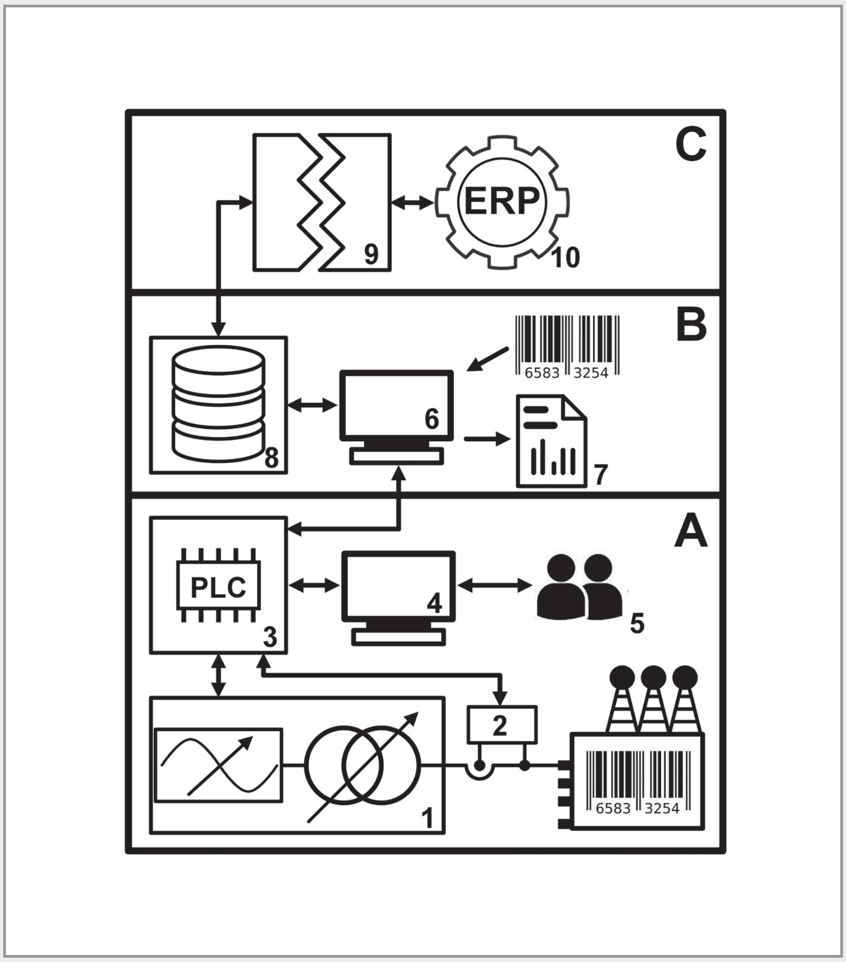


Figure 10. Levels of control in the system

In contrast to the mechanical reconfiguration of the transformer contacts by the test personnel, the time needed to establish a new test circuit arrangement is only limited by the switching time of the motor-driven isolating switches. Depending on the voltage class of the switch, this time is between 5 and 10 seconds.

8. Control levels of the test field

As well as speeding up the test procedure with automatic switch-over devices, optimised system control design can also deliver time savings, particularly through efficient processing of measurement data and automated generation of test records. If, in addition, the internal data management of the test system is linked with the transformer manufacturer's ERP system, the testing can be fully integrated into the manufacturer's business processes. The manufacturer-specific document management system can then be used, for example, to manage the transformer data, to create test instructions and to log test results. Central evaluation of the test results of produced transformers would open up many additional possibilities for quality assurance.

The typical control system used in the system can be divided into several hierarchically organised levels. This is shown in a simplified manner in Fig. 10, where the levels are designated by the letters A, B and C. Each higher-level element is characterised by an additional degree of abstraction and greater distance to the hardware of the test system.

The lowest control level (A) comprises the internal PLC (3), which directly controls the test system (1) in conjunction with a graphical user interface (4). The test personnel (5) must enter all electrical parameters that are relevant for the test manually at this control level. The required internal settings of the system are then made automatically by the PLC. The performance of adjustments and analyses for the load loss measurement (2) and the high-voltage measurement also takes place at this level. Thanks to the direct vicinity to the system hardware, special tests can be conducted here that differ from the standardised routine tests. The collected measurement results can be stored in a

A full integration boasts the advantage that the entire production cycle of the distribution transformer, including all test instructions, measured data and records, can be centrally managed in one system

raw data format by the PLC and then output for further processing.

Thanks to an extended control system (B), which is based on a special PC software (6) and a system-specific database (8), the level of manual input required on the test system for a particular test is reduced to typing in the serial number of the transformer under test. The test instructions, which contain all data that are relevant for a particular test, are prepared separately in advance and stored in the database. All collected measurement results, including those of the pre-tests of the transformer, are also stored in this database and can be matched easily to the tested unit through its serial number. Once all of the tests are completed, all data can be processed, combined and filed in a test record (7).

The highest degree of abstraction (C) is reached when the system-specific data management is linked through a coupling module (9) with the manufacturer's ERP system (10). Such a full integration, however, boasts the advantage that the entire production cycle of the distribution transformer, including all test instructions, measured data and records, can be centrally managed in one system. This makes it possible to reliably retrace all processes that are associated with the quality of the transformer at any time.

Conclusion

Considerations presented in Parts I and II of this paper have shown that through an automation of the individual work steps – setting up the test system, setting the test parameters, contacting the test object, modifying the test circuit, and creating a test report – the time needed for routine testing of distribution transformers can be significantly reduced. The greatest time savings are achieved mainly through a fully automated adjustment of the test voltage source and through the use of motor-operated disconnectors for switching the test circuit.

When initially outfitting a new test field, best results can be achieved when the control system is optimally matched to the hardware components of the test system. Our experience in several turnkey projects shows that the duration of a complete routine test on a transformer can actually be cut to less than 15 minutes. Compared to the duration of a complete test performed in a classic way without automation of control and switch-over, which takes about 25 to 30 minutes, it is possible to achieve a reduction in test time of about 40 percent.

Even in existing test fields it is possible to considerably speed up the daily testing routine by updating the control system, resulting in easier operation and an automatic execution of test sequences and creation of test reports.

Bibliography

[1] VDE 0532 Teil 3 2001-11 DIN EN 60076-3, Leistungstransformatoren - Teil 3: *Isolationspegel, Spannungsprüfungen und äußere Abstände in Luft*

[2] IEC 60076-1, *Power transformers – Part 1: General*, Second edition, 2000-03

[3] [42] IEC 60076-3, *Power transformers – Part 3: Insulation levels, dielectric tests and external clearances in air*, Second edition, 2000-03

[4] H. Abts, *Verteil-Transformatoren/ Distribution-Transformers*, Hüthig Verlag 2006

[5] Ake Carlson, Jitka Fuhr, Gottfried Schemel, Franz Wegscheider, *Testing of Power*

Transformers, Pro Print GmbH, 2003

[6] Nowak, Robert, *Automatisierung eines Prüffeldes für Verteiltransformatoren*, 2014

[7] A. Thiede, T. Steiner, R. Pietsch, *New Approach of Testing Power Transformers by Means of Static Frequency Converters,* CIGRE 2010 Session Paper D1-20

Compared to the duration of a complete test performed in a classic way without automation of control and switch-over, which takes about 25 to 30 minutes, it is possible to achieve a reduction in test time of about 40 percent

Authors

Dipl.-Ing. Raoul D. Harkenthal worked after his studies in electrical engineering at the Technical University of Dresden as a development engineer at OSRAM GmbH, and was later responsible for the development of Power Electronics at ENASYS GmbH. Since 2013 he has worked as a project manager for the development of test facilities for Distribution-Transformers at HIGHVOLT Prüftechnik Dresden GmbH.

David Kremzow holds a diploma degree from the University of Applied Sciences Dresden and has worked in the field of application development for more than a decade now. In the past he worked on different projects for the public sector before switching to his current engagement at HIGHVOLT Prüftechnik Dresden GmbH. Since 2015 he has been team leader of the software department at HIGHVOLT Prüftechnik Dresden GmbH with a strong expertise in measuring and controlling applications in the area of high voltage testing.